MANU Building – Bringing together Manufacturing Automation and Building Automation

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Abstract. Up to now, production systems only concern was to minimize production costs or optimize the utilization of production resources. But with the increasing energy prices and the growing concern over the environmental impact of production systems (industrial systems consume a quarter of all energy), efficient use of energy in manufacturing environment cannot be ignored any longer.
MANUbuilding concept brings together manufacturing systems requirements with building automaton concerns over the efficient energy use.

1 Introduction

Modern trends in automation require flexible production. While the current state of research shows a full range of solutions that satisfies mass customized dynamic production, it still assumes the constant level of energy consumption typical in centralized production with its long-time planning horizon.

However, existing production systems focus on production costs minimization, but ignore increasing energy prices and the growing concern over the environmental impact of production systems.

Therefore, the new automation paradigm would require not only flexible production but also adaptable energy management of a factory.

Energy efficiency is widely discussed these days. However, most of the research and most of the new solutions offered are aiming at smart grid systems [1,2] or energy savings in commercial and residential buildings [3]. In particular there is energy saving by including the industrial building is not investigated and there is a high potential for savings. The "building" (HVAC, lighting, water, alarms and security, occupancy) consume 40% of the industrial energy [3].

There are two main demands on industrial buildings: (a) providing a controlled stable environment for the production process challenged by the modern dynamic productions and (b) minimizing the energy required for this. The MANUbuilding concept joins together the manufacturing system with the building automation to optimize the overall energy consumption of a factory. The seamless interaction between building and production is crucial to overcome mutual negative effects existing today.

The MANUbuilding concept increases energy efficiency in the manufacturing environment (factory as a building) by developing distributed intelligent control system integrating knowledge from the building sensor and actuator network integrated with the available resources on the shop floor with the predictive analysis of the factory behavior based on the production plans and shop floor schedules. The resulting system provides:

1) a production driven building control concept that adapts building energy profile and behavior to the dynamically changing requirement of the production system represented by the Manufacturing Execution System (MES)

2) a control concept for building-aware production that would integrate the energy saving requirements of the building into production planning.

These goals serve a double purpose of optimization of both the energy use and production system performance. The concept is based on three pillars:

1) Cooperating objects – a sensor network concept combining sensor and actuators with intelligence represented by collectors that connect together and provide intelligence to different parts of the system (sensors, actuators, resources, MES, ERP, SCM) [4].

2) Function blocks – IEC 61499 is a modular, functionality based, event driven automation paradigm that is used as a platform for collectors implementation. It is the base for optimal integration in the production environment [5].

3) Distributed local decision making based on the dynamic expanding clusters where data fusion mechanisms are applied to find solutions in the most efficient way.

A solution providing substantial energy savings of 20 to 60%, while at the same time not restricting the flexibility of production and offering a convenient engineering will have a success on a 25 billion euro market (global building-automation market).

2 Integration of production planning and manufacturing environment

The main benefit of the MANUbuilding is in advanced concepts for efficient energy use in industrial environment based on function blocks with intelligent nodes and distributed algorithms that combine the production optimization requirements with the building energy saving goals. Taking into account physical parameters of the factory floor and ERP and MES production schedules MANUbuilding uses data fusion concepts to produce an efficient and safe yet cost efficient system for online energy monitoring of industrial buildings.

The two phase scenario of MANUbuilding allows making transition of existing system smoother: 1) In the first step the factory building adapts to the requirements of the manufacturing system, 2) And in the second step, the manufacturing system adapts its plans and behavior to consider energy needs of the factory.

Therefore, existing factories are able to use the system without changing their entire enterprise. The core of the MANUbuilding architecture is the concept of dynamically expanding clusters that calculate locally so-called Energy Health Status (EHS). The term EHM is inspired by the state of the art paradigm of Structural Health Monitoring

(SHM) where a sensor network monitors the structural integrity of a building structure.

EHM applies the principles of SHM to the energy monitoring area in order to determine integrity of the energy usage. EHM combines the concept of Cooperating objects with software agents' platform and energy efficient communication mechanisms, and applies net-centric, clustered multi sensor data fusion and processing algorithms to create a platform for online energy status retrieval.

2.1 Distributed decision-making based on dynamic clusters

The EHM approach focuses on recognizing and improving the Energy Health Status (EHS) of the system, where EHS is a resulting value of multiple calculations triggered by the events in the system that show the level of efficiency of energy use in a certain situation and location.

A simple example is when a user opens a window for full intermittent ventilation and temperature drops in a room. As a result a heater would start running. A simple solution to improve the EHS would be to stop the heater temporarily. In this way, the system can save the energy without interfering with user's intentions.

EHM system is based on expanding problem solving clusters to address the above mentioned drawbacks. Each cluster is a dynamically created community of intelligent components that cooperate with each to get enough information to solve a problem.

In case of the EHM, each member of a cluster has a set of algorithms that would allow recognizing an actual local EHS. In order to do so, it has to retrieve data from sensors and communicate with other members of the cluster to recognize and improve the EHS.

The initial creation of a cluster is trigged by an event that is predefined by the system developer or can be set by a user. In the case of the above given example, the cluster creation is initiated hen the window is open and the heater is on.

There is an endless number of scenarios possible from the very simple ones (as the above) to the very complex that involves regulation of the energy consumption on a scale of a complete building. The exact possible scenarios depend on the particular sensors related to an intelligent component as well as the location and designated tasks. The starting set of scenarios are assigned to a component during the initialization, but the new ones can be dynamically added during the system runtime when a new sensor or task is added to the system.

The key issue in developing such a system is flexibility and scalability of the solution. In EHM the problem solving approach is based on the expanding nature of the cluster formation and applied data fusion. Initially, there is only one member in the cluster that initiates and determines a problem. In the simplest case, its knowledge is sufficient to recognize the EHS and find an appropriate solution to improve it. But in the most cases it will require additional information and algorithms to improve the energy use efficiency.

Each intelligent component has a set of algorithms how to calculate and improve the EHS that has been assigned. And in order to do so, it needs to obtain information either from the sensors or from other intelligent units that also perform certain algorithms to calculate EHS. In EHM a brokering functionality is applied to find appropriate communication partners. Each system component publishes its algorithms and data points at the brokering component that manages the actual state of them via an event based update is triggered by the components themselves when a change in their algorithms occurs. The algorithm class description is encapsulated within a standard agent service description and can be understood by the collectors.

Hence, the system requires a very dynamic, flexible and scalable structure that includes both sensors and intelligent units to calculate the EHS.

2.2 System behaviour

EHM uses an emerging concept of Cooperating objects and sets its focus on sensor networks and distributed control that fits perfectly to fulfill the above mentioned requirements. Each Cooperating object consists of one or several sensors or/and actuators that are controlled by a collector. A collector is an intelligent component that has certain functionalities and is used in EHM for calculating the (local) EHS and participating in the cluster based solution finding.

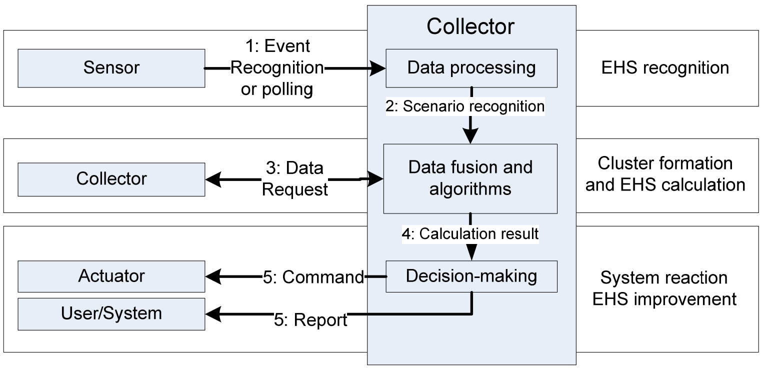

Fig. 1. Collector behavior

In the EHM architecture there are three main steps in a collector's behavior (Fig.1):

1. Raw sensor data retrieved by the collectors via polling or event-based mechanisms are processed locally. A single collector can be responsible for monitoring multiple sensors and has an ability to process and aggregate data.
2. A collector recognizes a scenario and if the processed data is not sufficient to calculate the EHS then a collector creates a cluster by contacting other collectors to retrieve required information. Each collector, depending on its functionality, has different data fusion algorithms to recognize and calculate the EHS.
3. If the collector cannot determine the EHS, then it expands the cluster to include collectors with more advanced algorithms that use the results of other collectors' calculations to recognize the EHS.

4. The final step is a decision making how to improve the EHS and the following (5) commands to the actuators and reporting to the upper level system control.

A flexible structure is one of the advantages of Cooperating objects concept that allow EHM to solve complex problems by including more collectors into the problem solving. Although, each collector in the EHM system is an independent acting entity, its position in the structure of the community is determined by the data management algorithms it can perform to calculate the EHS.

Some collectors in a cluster monitor one or few sensors and can only operate with the simple algorithms, on a higher level there are collectors that are not assigned to sensors but monitor other collectors and require the results of their calculations to perform more complex algorithms of their own. Due to the scalable structure of the Cooperating objects the number of collectors and resulting complexity is practically unlimited and hence allows the recognition of highly complex EHS.

However, it is important to mention that although the developed architecture allows dealing with complex algorithms requiring information from hundreds of sensors, in reality most of the situations can be dealt with a few collectors utilizing localized decisions.

All the computational and logical activities within the system are performed by the collectors making the choice of sensors and their integration into the system depend only on the ability to host the collectors. EHM uses sensors as hosts that provide the maximum flexibility to the system. Therefore, it is possible to spread the collectors over the existing sensor network.

The multi agent system that consists of a community of agents performing designated tasks as well as system components: an agent management system (AMS), directory facilitator (DF) and an interface to the upper level external system that allow EHM to implement a community of distributed collectors, provide a brokering functionality and use an existing communication platform [8].

Finally, data fusion and aggregation algorithms are applied to the collectors in context of software agents on WSN. Most data in monitoring are geographically or temporally correlated. And data redundancy can be avoided if the data were partially processed locally at the sensors by e.g., averaging it over time or space before forwarding [5]. There are several functions that can be used in data aggregation and fusion along its way to collectors. Examples of such functions include average, maximum, minimum, sum, or deviation that can be applied periodically or on-demand, such as delay-bounded and power-efficient data aggregation protocols. Most of the data fusion and aggregation protocols to be used in WSN net-centric environment are either centralized or do not consider power or delay efficiency. EHM applies data fusion and aggregation to the local problem solving hence minimizing power and delay concerns resulting in higher efficiency of sensor data usage.

2.3 Two phase scenario for energy efficient industrial environment

The proposed approach offers two possible implementation scenarios that allow a smooth transition from the existing systems to the energy aware productions.

In the **first phase**, MANUbuilding provides a production driven control of the building automation system, where the MES schedule will have a priority and the building will adapt its behavior to best fit the production needs

The uniqueness of the MANUbuilding approach is the way production schedule is understood by the underlying building automation system. This direct control allows saving energy on the one hand by dynamic reaction to events of the shop floor and on the other hand by being able to pro-actively react to future events derived from the MES schedule. High savings by the latter are in particular expected for inert functions such as cooling.

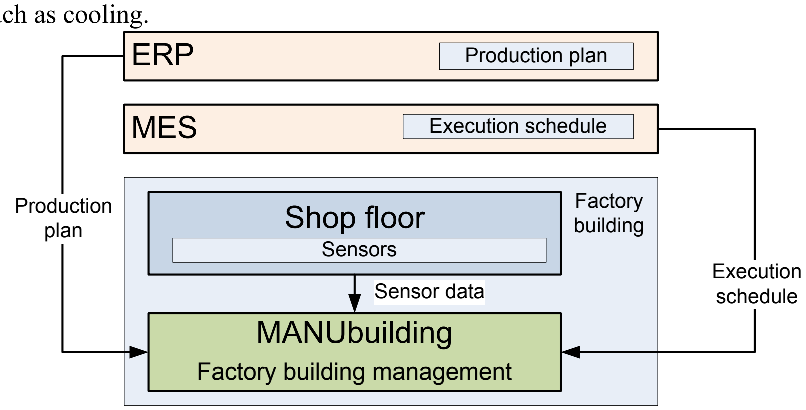

Fig. 2. Production driven control of the building automation system

As shown on Figure 2, MANUbuilding acquires three times of information:

- Production plans from the ERP; general, long-term planning on the enterprise level that allows planning factory maintenance depending on the shop floor project ted load. In this case MANUbuilding is able to more efficiently keep the required energy conditions and make transitions in the factory state smoothly.
- Execution schedule from the MES; short-term (minutes to hours, sometimes seconds) plan how certain operations are executed on the shop floor. In this case MANUbuilding behaves similar to the previous case with the different planning horizon and more local conditions up to a work cell or a robot. That allows a fine tuning of the shop floor, efficient energy use and longevity of the factory equipment.
- Sensor data from the shop floor as well as from the factory building in general. If the situations described above were proactive, then this case is a reactive behavior of MANUbuilding allowing to react on the events and critical situations on the shop floor that would usually require human supervision and a long command chain involved. Shorter reaction time (starting from the faster recognition to the actual reaction) save not only the energy of the factory but improves the production efficiency in general.

Within the first stage, there is no influence on neither production plan nor execution schedule from the MANUbuilding. All the improvements on the Energy Health

Status is implemented by the MANUbuilding system. The advantage of such a solution is the fact that practically any ERP or MES system can be utilized. However, the level of energy efficiency that can be achieved with the phase two is much higher.

Phase two implements a building-aware production system where both a building and the production planning will have mutual influence on the integrated system behavior combining production and energy cost parameters as criteria for system optimization. In this case, not only the building adapts to the production system, but also MES adapts it schedule to minimize the overall energy consumption of the complete factory (shop floor and surrounding building).

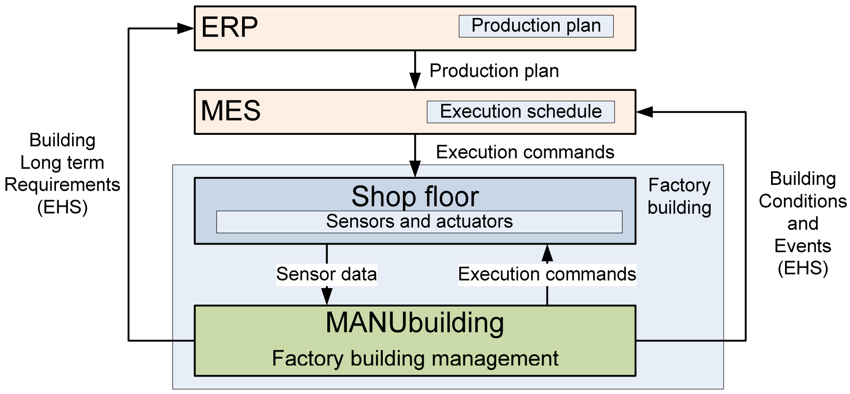

Fig. 3. Building-aware production system

Although not shown on Figure 3, phase two incorporates the activities of the phase one. Figure 4 only shows the extra communication that is performed during the phase two. The principal difference of phase two compare to phase one is that the production system considers energy requirements of the factory building in planning and operation execution. The mechanism is the following:

1. MANUbuilding sends long-term building energy requirements to the ERP system for the production plan decisions. Then it is a responsibility of the ERP system how to interpret this information: whether to include it into the planning or not. That requires the adjustment of the ERP system to be able not only to communicate with the MANUbuilding but also a set of rules and decision making procedures are required to implement MANUbuilding concept. Eventually, the energy requirements are passed down the MES system with the adapted production plan.
2. In addition to the long-term planning requirements, MANUbuilding sends events to the MES system to react on the changing energy profile of the factory during the runtime of the manufacturing system. These events are local and focused on particular sections or elements of the factory that change overtime. As with the ERP system it is up to the MES how to react to the events. And the MES system has to be adapted to be able to handle the communication and decision making procedures.

3. Finally, MANUbuilding itself may serve as management system on the same level as MES and issues commands to the shop floor to adapt to the energy requirements of the factory. Although, it might cause a conflict of interest in centralized MES solutions, recent developments towards distributed manufacturing systems are perfectly suited to handle such situations in a flexible, smooth and efficient way.

3 Outlook

The presented architecture bring together factory building management with the manufacturing system, but including factory energy requirements in the optimization decisions of the ERP and MES systems adjusting the formula of the total production costs that usually neglect energy costs of the production or count them as constant and therefore cannot be optimized.

The efficiency of the system lies in net-centric problem solution clusters that only extend themselves to larger aggregations if a problem cannot be solved on a local basis.

Two-phase solution offers flexible way of integrating MANUbuilding into existing systems without considerable changes to the already functioning environment.

However, the potential of MANUbuilding can be fully exploited in distributed manufacturing system, where MANUbuilding would be an integral part of planning and execution process, therefore, integrating energy costs and environmental concerns into the total production costs as a main criterion for optimization in manufacturing.

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